Fatigue of Teflon Bladder Bag Materials

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A correlation between fatigue and stress–strain behavior of Teflon materials was observed during a study of the fatigue properties of liquid propellant expulsion Teflon bladder bag materials. This correlation requires only the knowledge of the ultimate breaking stress of the materials in order to obtain an estimate of the fatigue properties, and permits a rapid assessment of the expected fatigue behavior of candidate materials for bladder bags from only a comparison of their ultimate breaking stress. The general principles of this method of fatigue analysis is discussed, along with the recognition that this technique should have general application for other polymeric materials where stress–strain behavior is comparable to Teflon.

Introduction

Bladder bags prepared from a standard Teflon film laminate and employed as liquid propellant expulsion devices were failing from the formation of tears and cracks near an aluminum seal ring which forms the mouth of the bag. The failures were occurring when the bags were filled with Freon-TF and isopropyl alcohol, employed as substitute fuels, and then vibrated during a simulated launch test. From a consideration of the conditions imposed on the bags during test, four factors believed most critical in contributing to the failures were identified for study: (1) flex fatigue, (2) biaxial stresses, (3) solvent sensitivity, and (4) crystallinity. The results of that study demonstrated that the primary cause for failure of standard laminate was its sensitivity to solvent stress-cracking (References 1 and 2), and that the bladder bags failed for that reason. A new material designated co-dispersion laminate was found to be insensitive to solvent stress-cracking and has replaced the standard laminate material used in construction of JPL Teflon bladder bags.

This article describes the flex fatigue properties of both standard and co-dispersion laminate materials. The study of these properties resulted in a method of fatigue analysis which should have general application. The concepts of the method and the fatigue properties of standard and co-dispersion laminate materials in particular are presented.

Bladder Construction

The construction of the bladder bags is detailed in Figure 1. Standard laminate is constructed in two plies, one of FEP 120 and the other of TFE 30. Co-dispersion laminate is constructed in three plies; an inner ply consists of FEP 9511 while the two outer plies are formed from a co-dispersion of 80% TFE and 20% FEP 9511.

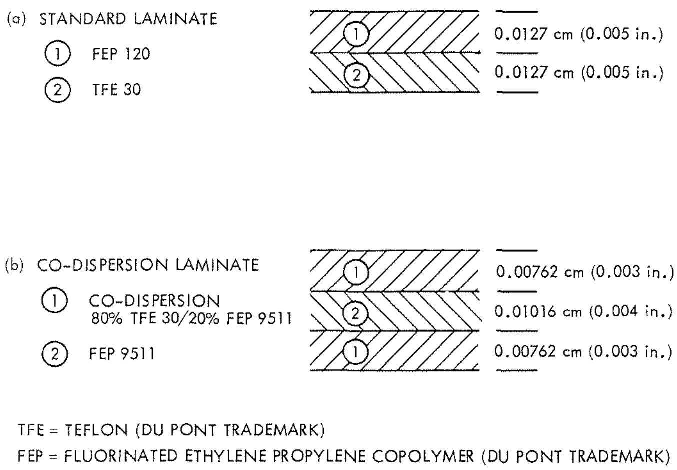

Figure 1. Bladder construction details

Fatigue Properties

Experiment

The fatigue properties of the Teflon materials were measured by cyclically stretching specimens on an Instron test machine to constant load and then correlating the number of cycles to failure with stress. For this study, dumbbell specimens of 0.0254-cm (0.010-in.)[1] thickness, 0.635-cm (0.250-in.) width, and 3.175-cm (1.25-in.) gage length were tested on the Instron operating at a crosshead speed of 0.423 cm/s (10 in./min).

Fatigue Results

The fatigue data for both standard and co-dispersion laminate materials are plotted in Figure 2 as the log of cycles to failure versus the maximum stress applied during the fatigue test. The data curve for the co-dispersion laminate is linear while curvature and a plateau are observed in the data curve for the standard laminate. This departure from linearity is believed to be caused by the tendency of standard laminate

[1] Where applicable, the International System of Units is stated first, followed by the customary units in parentheses. In each case, the value in parentheses represents the measured or calculated unit.

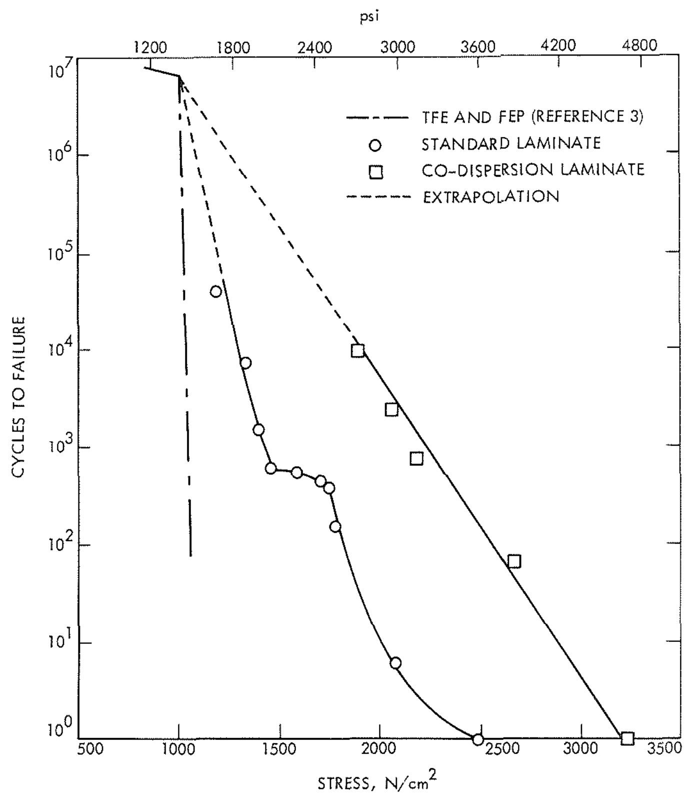

Figure 2. Fatigue properties of Teflon bladder bag materials

to delaminate during the fatigue testing. This point will be discussed later.

Both curves tend to converge to a common point near 10^7 cycles and to intercept the axis for one cycle at a stress which corresponds to their ultimate breaking stress (Figure 3). The convergence point at about 965-N/cm^2 (1400-psi) stress corresponds to the location on their stress–strain curves (Figure 3) where departure is observed from the initial linear relationship between stress and strain. This common convergence point has also been observed for fold fatigue studies (Reference 3) on FEP and TFE and has been defined as a fatigue endurance limit (this data is reproduced in both Figures 2 and 4).

These results demonstrate the existence of a correlation between fatigue properties and stress–strain behavior. For stresses within the linear portion of the stress–strain curve, fatigue failure occurs at about 10^7 cycles. But for stress exceeding those for linear behavior, i.e., in excess of the fatigue endurance limit, the number of cycles to failure decreases with increasing stress and the curves terminate at one cycle with a stress corresponding to the ultimate breaking stress. Thus, knowing the ultimate breaking stress, the fatigue properties can be predicted.

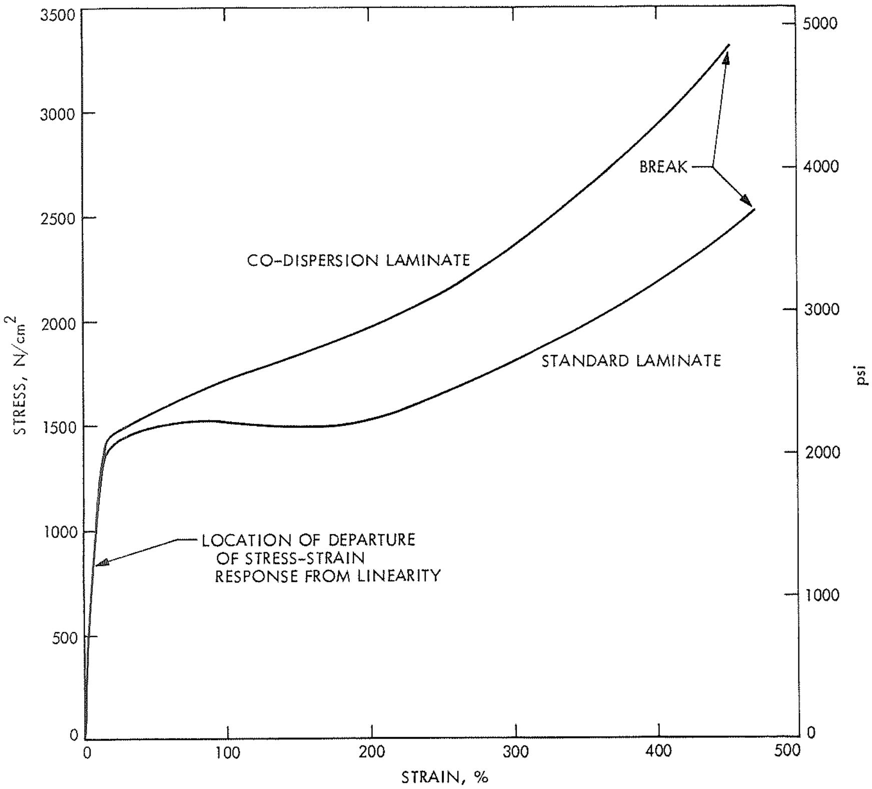

Figure 3. Stress–strain curves

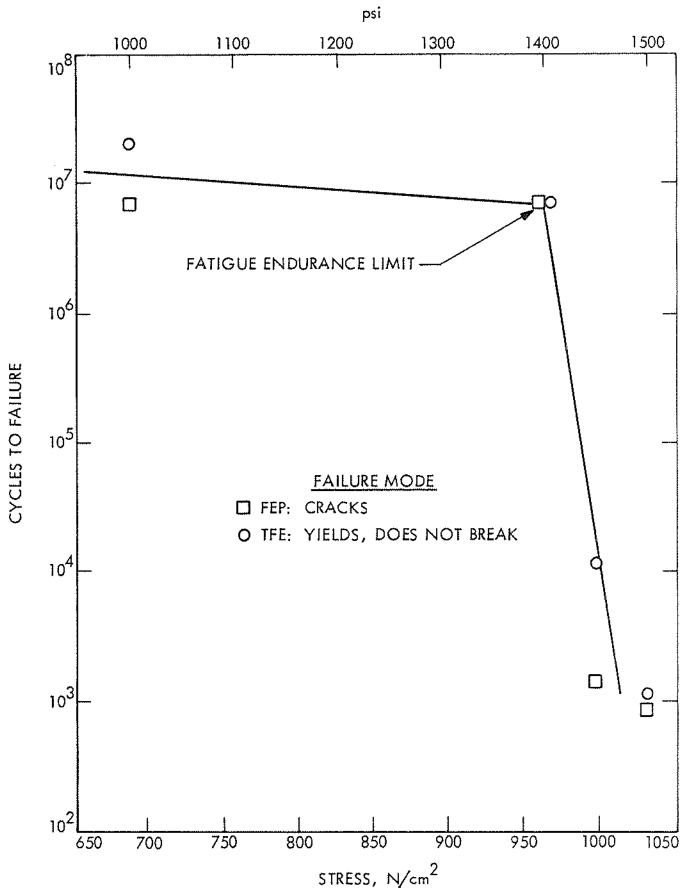

Figure 4. Fold fatigue of TFE and FEP (reproduced from data in Reference 3)

Delamination of Standard Laminate

All specimens of standard material delaminated during the fatigue testing, with the extent of delamination apparently reflected in the behavior of the data curve. For the cycle region above the plateau, substantial delamination was observed while negligible delamination was observed in the cycle region below the plateau. The plateau presumably occurs as the result of a transition from extensive delamination at high cycles to negligible and no delamination at low cycles. Delamination

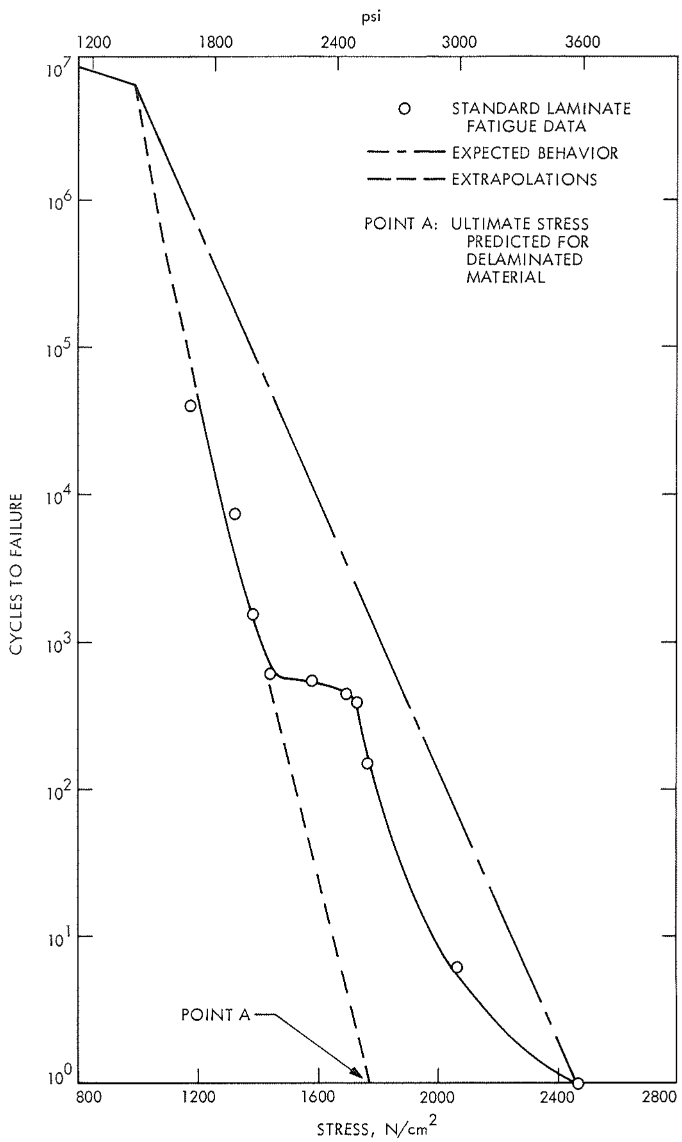

Figure 5. Comparison of actual standard laminate fatigue data with expected behavior

not only accounts for the departure of the standard laminate fatigue curve from linearity but also results in a substantial reduction in resistance to fatigue failure. This can be seen in Figure 5, where the fatigue curve is reproduced for this material along with the linear relationship expected for the absence of delamination.

One additional observation can also be made from Figure 5. The points above the plateau extrapolate to the 1-cycle line at an ultimate breaking stress of 1792 N/cm^2 (2600 psi). This value would presumably be obtained for a standard material delaminating during a uniaxial stress–strain measurement. This same value of ultimate stress was measured for standard materials which were tested while completely immersed in Freon-TF and heptane solvents (Reference 1), while exposure to isopropyl alcohol had an intermediate value near 2137 N/cm^2 (3100 psi). This suggests that part of the mechanism contributing to the solvent sensitivity of standard laminate may be a tendency to be delaminated by solvents.

Conclusion

The linear relationship between fatigue cycles and stress provides a simple method of fatigue analysis for Teflon materials. Given the ultimate breaking stress and the fatigue endurance limit, the fatigue properties can be predicted. Further, since the fatigue endurance limit is apparently common, a rapid assessment of the fatigue behavior of various Teflon materials can be made from only a comparison of the ultimate breaking stresses. Similarly the effect of environmental or other factors on fatigue properties can be inferred from their effect on the ultimate properties.

These considerations should also be applicable to materials having similar stress–strain characteristics as Teflon. These would include other crystalline polymers, such as polyethylene, and many block and graft copolymers including segmented urethanes.

References

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